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4. A similar calculation for the case in which the axis of the magneton is tangential to the path indicates that the rate of radiation is greater than that from the electric charge alone.

5. It should be noticed that if $v' = v'' = g'' = 0$ the expression for I vanishes. Hence when an electromagnetic pole and an electromagnetic doublet move together with constant velocity along a rectilinear path, it is possible for the moment of the doublet to change at a constant rate without there being any radiation of energy.

[1] *Electromagnetic Radiation*, Cambr. Univ. Press, 1912: *London, Phil. Mag.* (Ser. 6), 36, 1918, 243.

ON THE DISTRIBUTION OF THE APHELIA OF THE SECONDARY BODIES OF THE SOLAR SYSTEM

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The finding of a dependence of orbital eccentricity upon the relative masses of the components led to an examination of the directions of the aphelia of the secondary bodies of the solar system, a resumé of which is the principal object of the present paper.

There is little to guide us as yet in the interpretation of such a dependence. The first explanation which suggests itself is that it is a residual effect of capture. In the comets we have a very exaggerated effect of such a dependence. Their eccentricities are essentially unity and whether they come from interstellar space or from the outer planetary regions they are, for the few journeys which they perform about the sun, captured bodies. This is with reference to the comets with very long period and those with sensibly parabolic orbits. The relations of the orbits of those with comparatively short periods to the outer (and larger) planets establishes the fact that such comets have been captured for the sun by these different planets. We have, therefore, in the solar system at least one class of bodies which has been captured. A study of the orbital characteristics of these in connection with the other secondary bodies (having the sun also for primary) should disclose any similarities which may be significant.

One fact which stands out prominently in connection with this dependence of orbital eccentricity upon relative mass appears to be significant. There are two possibilities aside from that of *no* preference of eccentricity for relative mass: (a) the preference may be of larger eccentricities for systems with the *smaller* relative masses for the secondaries, or it may (b) be the reverse, a preference of the larger eccentricities for the systems with the *larger* relative masses for the secondaries.

The first of these possibilities is the one of which such widely distributed evidence has been found. Such a condition appears to result naturally from capture.

The second possibility (b), on the other hand, could not result from capture, nor does evidence of such a condition appear to prevail in nature.

It cannot but be regarded as significant, therefore, that of three possibilities the one which is actually found to prevail in nature is the one which would result directly from capture. The evidence is not sufficient to establish from the observed preference the reverse reasoning, viz., that because of this observed preference it must be concluded that binary and planetary systems have resulted from capture. It must be admitted, however, that this observational evidence, which appears to be stronger than any as yet adduced for a process of fission, places a theory of capture in a new light, and requires that it be seriously considered, not only for the solar system but for stellar systems as well.

If the secondary bodies of the solar system have been captured, and providing no force has seriously disturbed the major axes of their orbits since, or disturbed them all equally, we might expect to find a preference of the directions of their aphelia for some particular region of sky. It does not necessarily follow that it would be the region of the apex of solar motion. Differences of direction or velocity in the *relative* motions of the sun and the secondary bodies previous to capture could conceivably cause an apparent preference of their aphelia for almost any part of the sky.

The following four diagrams give in condensed form the results of an examination of the aphelia of the 8 major planets, 821 minor planets, 45 comets with periods of less than 80 years and 364 comets with longer periods and essentially parabolic orbits.

It is impossible to give in a limited space a full summary of the considerations resulting from this examination which has included not only the directions of aphelia but the orbital inclinations, longitudes of the nodes, galactic relations, etc. A full account of the investigation will be published in another place.

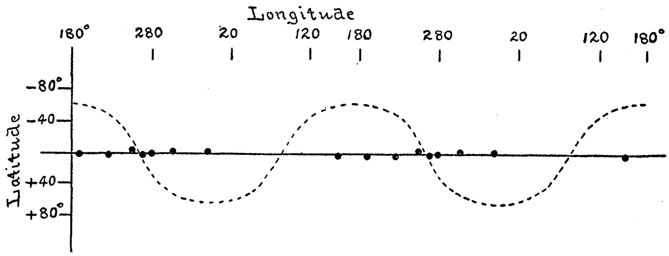

FIG. 1. APHELIA OF MAJOR PLANETS

Dotted line is the Galactic Plane

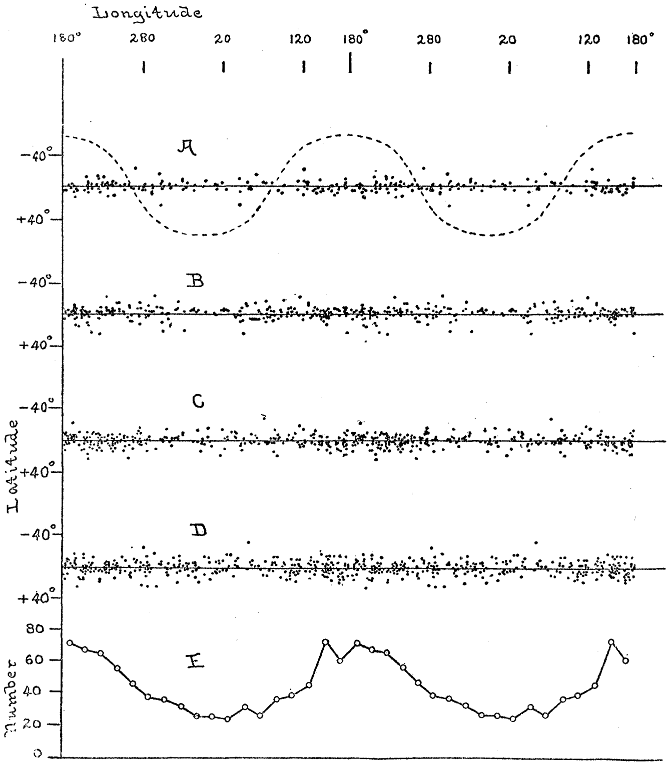

FIG. 2. APHELIA OF 821 MINOR PLANETS

A. Nos. 1 to 120 inclusive
B. Nos. 121 to 320 inclusive
C. Nos. 321 to 560 inclusive
D. Nos. 561 to 821 inclusive
E Frequency curve in longitude (all).

The following is a summary of the conclusions indicated by this investigation:

1. The axes of the orbits of the major planets, minor planets and short-period comets are all closely related to the ecliptic plane. This condition has been known in a general way.

2. The aphelia of the eight major planets are confined to the half of the sky whose center is the longitude of the apex of solar motion. Their longitudes are arranged almost symmetrically with respect to that point. The center of preference in direction of the aphelia of these bodies is, therefore, the intersection of the ecliptic and galactic planes.

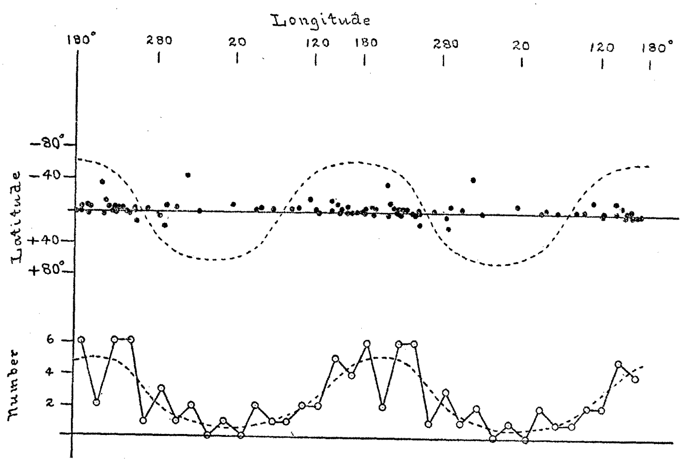

FIG. 3. APHELIA OF SHORT-PERIOD COMETS (UPPER). FREQUENCY CURVE OF SAME IN LONGITUDE (LOWER)

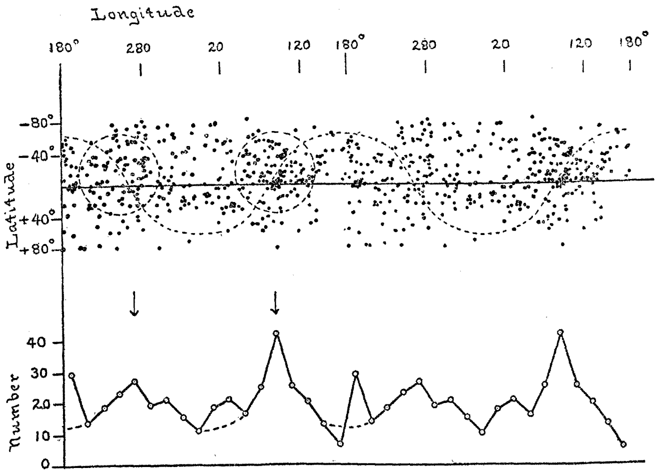

FIG. 4. APHELIA OF 364 PARABOLIC AND LONG-PERIOD COMETS. B.C. 371 TO A.D. 1914. FREQUENCY CURVE IN LONGITUDE (LOWER)

3. The aphelia of the minor planets show a consistent and strong preference for longitudes in the region of 195°. The curve of preference

is closely a sine curve with the maximum at 195° and the minimum at 15°. There are indications of variations of a shorter period superposed on this curve which can be explained by more or less harmonic gaps at certain longitudes.

4. The aphelia of the 45 short-period comets show a preference for essentially the same longitude as do the minor planets, viz., 195°, the minimum occurring also at 15°. Considerable irregularities exist in this curve, due largely to the small amount of data. Some of the irregularities, however, appear to exist in the curves of parabolic comets also. The general form of the curve is none the less well marked.

5. The aphelia of the parabolic (and very long-period) comets show a preference for a region near the intersection of the ecliptic with the galaxy which is nearest to the longitude of the antapex of solar motion (90°). A more widely scattered and less pronounced preference is shown for the region of the longitude of the apex of solar motion (270°). There appears to be a tendency to avoid the intermediate galactic regions, between these two regions of preference and also the galactic polar regions.

6. Although the aphelia of the parabolic comets are widely distributed over the sphere, there is a small preference for the ecliptic plane. The deficiency of aphelia is most marked in the region of the northern pole of the ecliptic ($\alpha = 18^h$, $\delta = +67°$).

7. There is a deficiency of small inclinations (to the ecliptic) among the parabolic comets which is nearly normalized if the short-period comets are included. This indicates that these short-period comets have been captured out of the general herd and that their inclinations have not been radically changed since capture.

The distribution of the aphelia of the parabolic comets is what might be expected if they have been captured from bodies which are more plentiful in the galactic regions than elsewhere.

On the theory of probability only a very small proportion out of a mass moving with all directions and speeds would come close enough to be observable from the earth, except such as were moving with nearly the same speed as the Sun when they came within the distance of effective gravitational action. All of such, except those changed into small ellipses by planetary perturbation, will have sensibly parabolic motion. Preponderance of aphelia in the southern ecliptic hemisphere as well as the southerly ecliptic deviation of the maxima near the longitudes of the solar apex and antapex, indicate some sort of preferential motion of these bodies with respect to the Sun before capture. The general preference of the aphelia of these comets for the longitudes of the solar apex and antapex can scarcely be a relation other than to the sun's motion among the stars. The greater condensation and preference for the longitude of the antapex appears to be real. Such a condition might perhaps follow if the cometary bodies were moving in general more rapidly than the Sun.

To summarize, the short-period comets show a preference of their aphelia for the same ecliptic longitudes as do the asteroids, but radically different from the distribution of the parabolic comets and those of very long period. As the short-period comets are conceded to be captures, has a similar preference of aphelia in the case of the asteroids also resulted from capture or is it due to some other cause? It is conceivable that such a preference might result from gravitational effects of the stellar system. If so why do the major planets show a different preference? The longitude of Jupiter's aphelion is at present approximately 192°, sensibly that of the preferences of the minor planets and short-period comets. Is there any connection? The moderate eccentricity of Jupiter's present orbit does not tend to strengthen a belief in such a relation.

It seems rather more than coincidence that the aphelia of all of the major planets are confined to one half of the sky and that the center of preference coincides so closely with the longitude of the sun's direction of motion in space, notwithstanding the observed revolutions of their lines of apsides, which differ greatly among themselves. Can it be that there are compensations or that our one or two centuries of (accurate) observations are insufficient to disclose gravitational or other effects of the stellar system? or does the mean of the planetary longitudes follow a changing direction of solar motion?

It is perhaps possible to believe that the observed preference of the major planets is coincidence, but not so the preferences of the minor planets and the comets. They are too numerous and their preferences too consistent. These unquestionably indicate a common underlying cause.

The parabolic comets show a very sharp maximum of aphelia at approximately 190° (fig. 4) preceding the one at 270° in some such way as the one at 20° precedes the strongest maximum of all at 90°. A division of the data into two groups shows the same peculiarities, indicating that it is real. This sharp maximum at 190° is perhaps significant, in connection with the similar preference of the minor planets and short-period comets for the same region.

This investigation has suggested a possible physical cause for the position of the ecliptic plane which, so far as I am aware, has not been satisfactorily accounted for. It is purely speculative and I know of no test which would be adequate, particularly as it rests upon the theory of capture which is far from being established. This explanation was suggested by the fact that the ecliptic intersects the galaxy not far from the extremities of the axis of preferential motion. There is some evidence that the two star streams may be in reality parts of a *curved* stream, the so-called axis of preferential motion being in reality a tangent to that curve. In my opinion such a conception best satisfies the observed conditions. Radial velocities indicate maxima to the *south* of both extremities of the so-called ellipsoidal axis. This brings the intersection near 18^h in the general region of what appears to be one star stream.

The centers of preference of the parabolic comets near the longitudes of the apex and antapex of solar motion are also both some 10° or 15° south of the ecliptic. If now the planets were captured, it is not difficult to outline a cause for the position of the ecliptic. Bodies moving with a stellar stream (not to be more definite at present) might be picked up by the Sun and if acted upon by a resisting medium, have their orbits rendered nearly circular. By mutual perturbation their orbits would tend to assume a common or 'invariable plane.' The addition of the masses of the satellites, comets and asteroids would not greatly disturb this plane, once established. This accounts for only one coordinate of the plane. The other we must suppose to be the mean of the group and as far as we know, at present, accidental.

This hypothesis is admittedly speculative and further discussion at this time does not seem warranted.

DISCOIDAL STRUCTURE OF THE LITHOSPHERE[1]

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Communicated by J. M. Clarke, July 15, 1919

Underlying the thesis here presented are the following postulates:

a. The lithosphere is heterogeneous as to density;

b. The lighter and heavier masses are of notable dimensions, varying from a hundred to several thousand kilometers in diameter;